The Use of Microgravity Simulators for Space Research

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ABSTRACT

The spaceflight environment is known to influence biological processes ranging from stimulation of cellular damage repair, suppression of immune functions, and bone and muscle loss in astronauts. Microgravity is one of the most significant stress factors experienced by living organisms during spaceflight, and therefore, understanding cellular responses to altered gravity at the physiological and molecular level is critical for expanding our knowledge of life in space.

Since opportunities to conduct experiments in space are scarce, various microgravity simulators and analogues have been widely used in space biology ground studies. Even though simulated microgravity conditions only produced some, but not all of the biological effects observed in the true microgravity environment, they provide test beds that are effective, affordable, and readily available to facilitate microgravity research.

Kennedy Space Center (KSC) provides ground microgravity simulator support by offering a variety of microgravity simulators and platforms for Space Biology investigators. Assistance will be provided by KSC experts in molecular biology, microgravity simulation, and engineering. Comparisons between the physical differences in microgravity simulators, examples of experiments using the simulators, and scientific questions regarding the use of microgravity simulators will be discussed.

KSC Microgravity Simulation Support

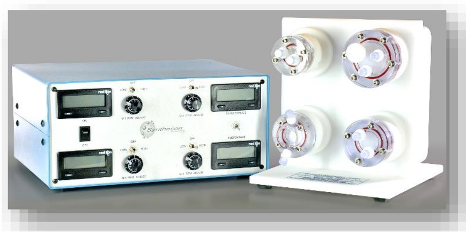
Ground Microgravity Simulation Support at KSC is being established for short duration studies utilizing a variety of microgravity simulator devices that negate the directional influence of the “g” vector for Space Biology investigators. Experiments using ground microgravity simulations can serve as secondary ground controls to ISS studies.

The simulators include, but are not limited to; 2D Clinostats, 3D Clinostats, Random Positioning Machines, and Rotating Wall Vessels. Assistance will be provided by KSC experts in molecular biology, microgravity simulation, and engineering.

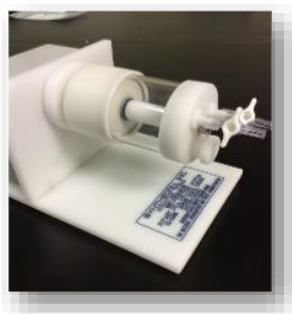
These gravity simulators can be accommodated within controlled environment chambers allowing investigators to customize and monitor environmental conditions such as temperature, humidity, CO_2, and light exposure.

Ground Microgravity Simulation Devices

Rotating Wall Vessels



Customized High Aspect Ratio Vessel (HARV) Systems



Schwarz-Trinh Lateral Vessel (STLV)

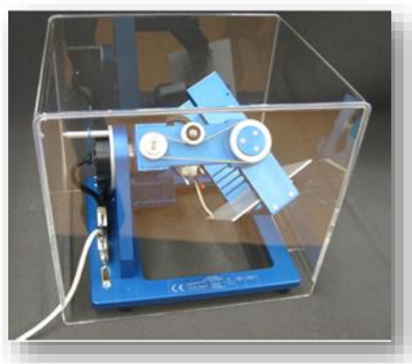
STLV Perfusion System

- Rotating Wall Vessels (RWVs; or bioreactors) were originally invented by NASA and have been successfully used to investigate gravitational effects on biological specimens such as cell cultures, aquatic organisms (zebra fish eggs/embryos), tissue cultures, etc.
- Microgravity effects are simulated within liquid media by RWVs and are studied by aligning cultures on a rotating horizontal axis at a defined rotational speed that regulates the fall velocity, thereby allowing specimens to remain in constant free fall to simulate near weightless conditions.
- Some studies have shown that morphological and structural changes in cells cultured in rotating wall vessels resemble those observed *in vivo* after exposure to microgravity during spaceflight.
- HARV, STLV, STLV perfusion systems, and HFB are alternative types of RWV systems that are utilized for different cell models ranging from stem and immune cells to 3D tissue aggregates.

3D Clinostats

Space Bio-Laboratories Gravite

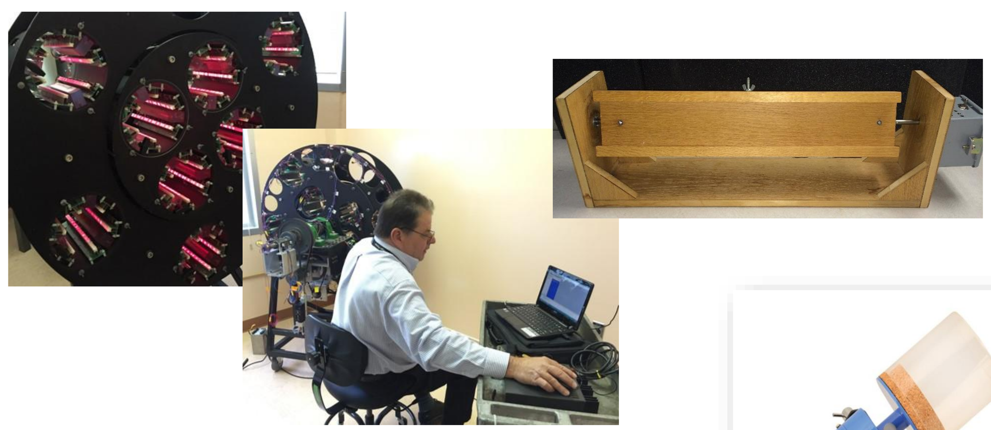
Advanced Engineering Services PMS-X

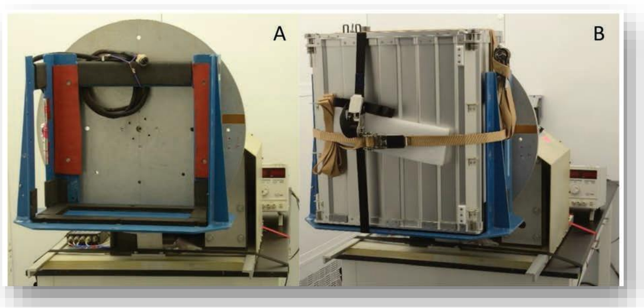


Airbus RPM 2.0

- 3-D clinostats have two independently rotating frames that are mounted perpendicular to each other. The term “3-D clinostat” is used when both rotating axes of the device are running with constant speed and constant direction.
- However, both frames can also be operated with different speeds and different directions, in which case the term “random positioning machine” is often used. Randomness is achieved when the rotational angle differs between the two axes and changes over time.
- An experimental apparatus containing research specimens is placed within the inner of two counter-rotating platforms. Modifications to the inner platform can allow use of various hardware configurations (up to 6 kg on PMS-X).
- Two RPM versions are currently available at KSC, the Airbus RPM 2.0 and the Space Bio-Laboratories, Inc. GRAVITE. Based upon operating configurations, treatments of simulated microgravity ($<10^{-3}$ g), partial gravity, or hypergravity (to 2-3 g) can be achieved.

2D Rotating Clinostats





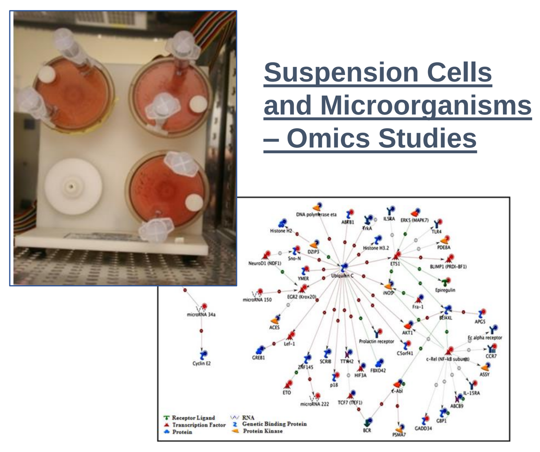
Various 2D Clinostat Models

- KSC engineers have designed a slow rotating clinostat that allows researchers to subject biological specimens contained within ISS stowage lockers (containing hardware used for spaceflight experiments), or other large containers, to simulated microgravity conditions.
- The clinostat rotates in one dimension along the horizontal axis at 2-4 rpm. Power is provided for built-in computers, lamps, fans, and auxiliary equipment.
- Adapters can be developed to accept various hardware configurations.
- Other slow rotating clinostats are also available for 10 cm x 10 cm Petri plates and other containers specialized for particular life science model organisms.

Microgravity Research

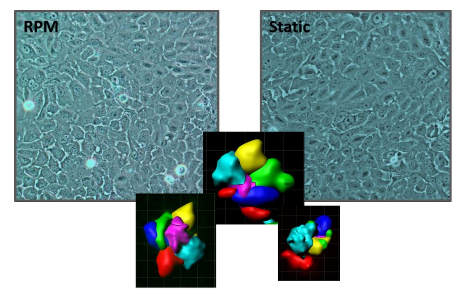
Microgravity is one of the most significant stress factors experienced by living organisms during spaceflight, and therefore, understanding cellular responses to altered gravity at the physiological and molecular level is critical for expanding our knowledge of life in space.

Examples of Biological Studies Using Microgravity Simulators

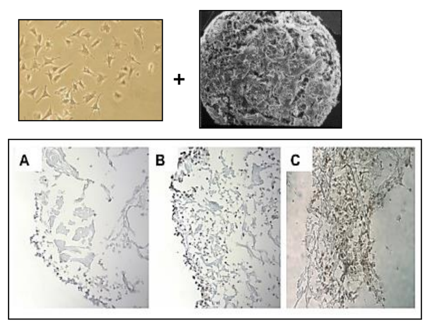


Suspension Cells and Microorganisms – Omics Studies

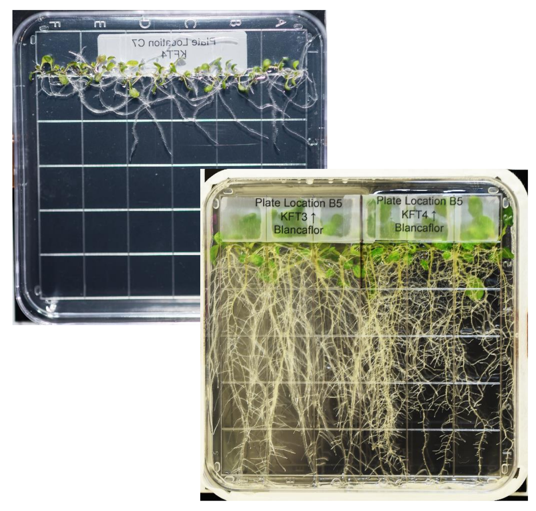
Adhesion Cells - Cytoskeleton, Nuclear, and Chromosomal Structures



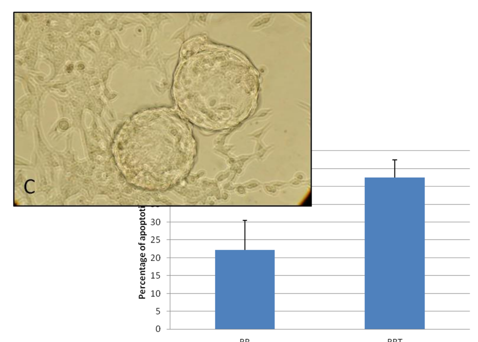
Bone Cell Differentiation



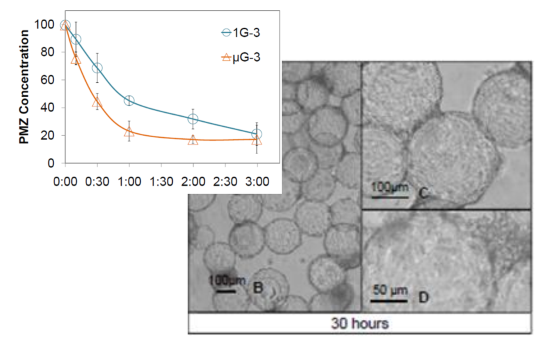
Plant Research



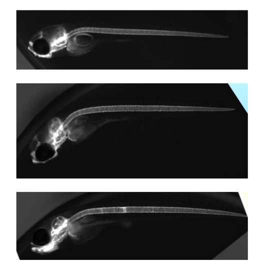
Sensitivity of Cancer Cells to Cell Killing Effects of Chemo-drugs



Liver Cells and Drug Metabolism



Embryo Development



Research Gaps

Simulated microgravity conditions ~~have~~ produced some, but not all of the biological effects observed in the true microgravity environment. Research topics of interest using ground-based microgravity simulators include, but are not limited to:

- Comparing and validating the effectiveness of micro-g to hyper-g simulations using various ground simulation models.
- Analyzing the differences between true microgravity and simulated microgravity and between existing micro-g simulators using theoretic mathematical models.
- Developing new micro-g simulators or modifying existing designs.
- Investigating the biological effectiveness of modeled micro-g and partial-g in different cell types at different developmental stages.
- Evaluating the biological effectiveness of modeled micro-g and partial-g in cells at different cell cycle stages.
- Determining the biological effectiveness of simulated micro-g and partial-g using 2-D vs 3-D cell models.
- Investigating the biological effectiveness of simulated micro-g and partial-g on subcellular component formation, conformation, and interaction.
- Evaluating synergistic biological effects of simulated microgravity in combination with other space environmental factors.

Conclusions

Even though simulated microgravity conditions only produced some, but not all of the biological effects observed in the true microgravity environment, they provide test beds that are effective, affordable, and readily available to facilitate microgravity research.

Analyzing similarities and differences between biological responses in living organisms to true microgravity and simulated microgravity is critical for understanding the effects of Gravity as a Continuum. In addition, the comparison and validation of the effectiveness of micro-g to hyper-g simulations using various ground simulation models is important for species specific data interpretation.

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